Annual Project Summary

Determination of a High Resolution Paleoearthquake Chronology for the Northern San Andreas Fault at the Vedanta Marsh Site, Marin County, CA

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Element II: NEHRP research priorities to understand earthquake occurrence and effect

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Investigation undertaken:

The main objective of this NEHRP research is to obtain a high-resolution chronology of paleoearthquakes on the 1906 rupture trace of the San Andreas fault in Marin County and to determine slip-per-event of pre-1906 earthquakes through detailed three-dimensional excavations. Determining the timing of past San Andreas fault earthquakes has great significance for the long-term seismic hazards of the densely populated San Francisco Bay region. The results of this research will be used to test earthquake rupture models of the San Andreas fault and to improve the earthquake probability estimates published by the U.S. Geological Survey. The anticipated outcome of this research will be a better definition of the earthquake cycle in the San Francisco Bay area.

This research is being conducted at the Vedanta paleoseismic field site in Olema, Marin County, CA. The Vedanta site has all of the elements that promise to provide a high-resolution paleoearthquake chronology for the past 3000+ years. The fault zone is wide with multiple fractures and definable event stratigraphy. The layers contain *in situ* organic material that will provide age control. The margins of channel deposits, downed Douglas fir trees, and the margins of landslide debris lobes detected in trench exposures can provide piercing points to match across the fault in order to determine paleo-slip. We plan to recover these paleoseismic data in 3-D excavation during a 2004 field season. Following is a summary of research conducted during the 2002-2003 year of this project.

During the past year, the data from all the trench exposures across the San Andreas fault at the Vedanta paleoseismic site were analyzed. The marsh stratigraphy was classified and correlated between the trenches (Figure 1), and event evidence was identified in each trench wall (Figure 2). Eight trenches and a large 4-m deep V-ditch (Trench D) have been excavated across the northern San Andreas Fault on the Vedanta Retreat property in Olema, CA in recent field seasons. The initial purpose of digging Trench D was for de-watering the study site in the marsh. Surprisingly, Trench D, especially its north wall, contains a well preserved, very detailed, and continuous record of earthquakes over the past 3000 years. During the 2002 field season, Trench D and trenches VT-1 and VT-3 were reopened. A new trench (VT-8) was excavated in the bottom of Trench in order to extend the paleoearthquake chronology back into earlier strata. Trench VT-8 was very unstable because of high water flow. Two new, shallow trenches were excavated across the San Andreas fault. The main goal of these trenches (VT-6 and VT-7) was to gather more evidence for the timing the Penultimate event. The south wall of Trench VT-1, the north wall of Trench VT-3, and north and south walls of the V-ditch were successively peeled back and logged in order to gain further insight into the event horizons at the site.

In the field the stratigraphic boundaries and fault planes were identified and mapped. Digital data was collected using a Total Station survey. All the trench walls were photographed using a 0.5 m by 1.0 m or 0.5m by 0.5 m photo grid spacing. The photos were mosaiced together. The trench exposures were logged on both paper and the photomosaics.

More than fifty radiocarbon samples were collected during the 2001 and 2002 field season. Although organic materials are abundant at this marsh site, extremely careful work was taken during the sampling in order to eliminate the uncertainties caused by sedimentary rework, fault activity, or bioturbation. Samples were collected after careful inspection based on their important relationship either to the stratigraphic boundaries or to the event horizons. Pollen and soil samples were also collected in order to reconstruct the sedimentary environment. We did not conduct fieldwork in 2003. Data were processed and interpreted in 2003.

Results:

The Vedanta paleoseismic marsh site is an exceptional site because nowhere else on the northern San Andreas fault has a site been found where predominately fine-grained, organic-rich deposition has continuously buried the fault during the Holocene. The Vedanta marsh stratigraphy contains peat and clayey silt layers with abundant sticks, leaves, charcoal, and other *in situ* organic matter ideal for radiocarbon analyses. The main results of the research to data include the development of a generalized stratigraphic sequence that correlates each sedimentary layer exposed in each of the trenches (Figure 1) and the establishment of earthquake event horizons across the site (Figure 2). Final photo logs of each trench wall were drafted using Adobe PhotoShop

5.0 and Illustrator 7.0 software program. Figure 3 shows the 4.5 m thick sedimentary section and fault stratigraphy exposed in the Trench D north wall.

Radiocarbon analyses are a crucial element in the determination of a high resolution earthquake chronology. Careful interpretation of the sample types, sample locations, and possible contamination must be made. Because the carbon in a peat may have different sources, there is some scatter of the age determination for each of the layers and a minor amount of stratigraphically reversed age results. This is particularly true in the upper bioturbated, coarse clastic section of the trenches. Most of the lower stratigraphic section lies below the water table and has not been bioturbated by burrowing animals. Our analyses combine radiocarbon age results from the 1998 BAPEX study at the site with 54 radiocarbon dates provided from samples collected during the 2001 and 2002 NEHRP field season. Radiocarbon dates were provided by the Center for Accelerator Mass Spectroscopy at the Lawrence Livermore National Laboratory. Interpretation of the radiocarbon dating ages for each of the key stratigraphic horizons is still in progress.

At the Vedanta paleoseismic site, eleven pre-1906 earthquakes have been identified in the stratigraphic section based on outward-splaying, upward fault terminations and fissure fills. The 1906 earthquake (Event I) ruptured a portion of the upper gravel, and based on historical data, caused a 5 m right-lateral offset of ground surface near the site. Deformation within each of the laterally correlative, upper three peat layers deposited about 300, 700, and 1100 yr B.P. exposed in all the trenches provide age constraints on the timing of four pre-1906 earthquakes (Events II-IVB). Earlier events were exposed in the one deep excavation (Trench D) and were identified in the stratigraphic section dated to approximately 1200 to 2500 yr B.P. Most of the event horizons terminate in or near major *in situ* peat layers that provide excellent organic material for radiocarbon analysis. Correlation between trenches and radiocarbon dates indicates a range of recurrence intervals between paleoearthquakes. Further analyses of the radiocarbon data using the Oxcal program is still in progress. The age data will help us to clearly define the dates of the paleoearthquakes on the northern San Andreas fault at the Vedanta site. The data from this study are being analyzed by UMKC graduate student Hongwei Zhang as part of his doctoral dissertation.

Non-technical Summary:

At the Vedanta paleoseismic site located in Olema, 60 km north of San Francisco, well-defined stratigraphy and abundant *in situ* organic material allow the determination of the first long, high-resolution multiple-event record for the north coast segment of the San Andreas fault. Trench excavations across the fault show a 2-m-wide main fault zone of upward-branching fault splays within the marsh. Twelve earthquakes including the great 1906 San Francisco earthquake appear to have ruptured this portion of the San Andreas fault over the past 3000 years. Correlation between trenches and radiocarbon dates indicates a range of recurrence intervals between paleoearthquakes.

Reports published:

Zhang, H., Niemi, T.M., Generaux, S., Fumal, T., and Sietz, G., 2003, Paleoseismology of the Northern San Andreas fault at Vedanta marsh site, Olema, California (abst.): XVI International Quaternary Association Congress, Reno, NV, July 23-31, 2003.

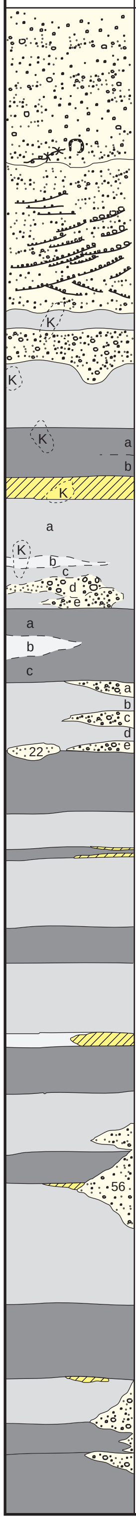
Zhang, H., Niemi, T.M., Generaux, S., and Fumal, T., 2003, Earthquake events and recurrence interval on the northern San Andreas fault at Vedanta marsh site, Olema, CA (abst.): North-Central Section Meeting of the Geological Society of America, Kansas City, MO, *GSA Abstract with Program*, v. 35 (2), p. 58.

Generaux, S., Niemi, T.M., and Burns, R., 2003, Evidence for the Pleistocene-Holocene transition form a 20.8m core obtained from Vedanta Marsh, Olema, CA (abst.): North-Central Section Meeting of the Geological Society of America, Kansas City, MO, *GSA Abstract with Program*, v. 35 (2), p. 53.

Generaux, S., Niemi, T.M., Zhang, H., 2002, Historical pollen as an indicator for constraining earthquake stratigraphy along the San Andreas fault, Vedanta Marsh, Olema, CA (abst.): Annual Meeting, Geological Society of America, Denver, CO, *GSA Abstract with Program.*

Availability of processed data:

Trench logs are available in Adobe PhotoShop 5.0 and Adobe Illustrator 7.0 format, or in Adobe Acrobat PDF format. Carbon-14 data is in Word 97 or Excel 97 format. Contact Dr. Niemi for further information: NIEMI, Tina M., Department of Geosciences, University of Missouri - Kansas City, 5100 Rockhill Rd., Kansas City, MO 64110, niemit@umkc.edu;

Stratigraphic Sequence	Average Layer Depth (cm)	Layer (-sublayer) Number	Average Layer Thickness (cm)	Descriptions	Munsell Color*	Ages (calendar years)
	0	1	50	Dark gray or dark grayish brown gravelly mud or muddy gravel Post-1906 deposits and spoils with artificial works such as barbed wire, horse shoe and road pavement. Soft with dense grass or tree roots.	10 YR 4/1 - 4/2	
	50	4	50	Gray to light yellowish gray sandy gravel. Most gravel clasts have reddish yellow Fe-oxide coating. A channel deposit with distinct graded bedding and cross stratification.	10 YR 6/1 - 6/4	
	100	5	7	Very dark gray sandy clayey silt.	10 YR 3/1	
	107	6	12	Dark brown muddy gravel.	10 YR 4/4	
	119	9	20	Gray or dark gray peaty silty clay.	10 YR 5/1 - 4/1	
	139	10 - a, - b	17	Dark gray silty clayey peat. This layer can be further divided into two sublayers.	10 YR 4/1	
	156	11	7	Brown clay with light gray or yellowish red motting.	10 YR 5/3	
	163	12 - a, - b, - c, - d, - e	37	Dark gray peaty silty clay. This layer can be further divided into five sublayers.	10 YR 4/1	
	200	20 - a, - b, - c	24	Dark gray to very dark gray woody clayey peat. In trench 4 this layer shows three sublayers.	10 YR 4/1 - 3/1	
	224	21 - a, - b, - c, - d, - e	23	Gray to dark gray clay. This layer interfinger eastward with ridge-derived colluvial gravel and can be divided into five distinct sublayers.	10 YR 5/1 - 4/1	
	247	22	15	Gray to very dark gray sand or fine gravel.	10 YR 6/1 - 3/1	
		30	20	Dark gray to very dark gray woody peat.	10 YR 4/1 - 3/1	
	267	31	12	Gray to dark gray peaty silty clay.	10 YR 5/1 - 4/1	
	279	35	4	Gray to dark gray woody clayey peat or gravelly peat.	10 YR 5/1 - 4/1	
	283	36	23	Gray to dark gray silty clay.	10 YR 5/1 - 4/1	
	306	40	12	Dark gray clayey peat.	10 YR 4/1	
	318	41	23	Gray to dark gray silty clay.	10 YR 5/ 1 - 4/1	
	341	42	5	Light gray to gray clay.	10 YR 6/1	
	346	50	15	Dark gray clayey peat.	10 YR 4/1	
	361	51	20	Gray to dark gray silty clay.	10 YR 5/1 - 4/1	
	381	55	10	Dark gray clayey peat.	10 YR 4/1	
	391	56	20	Dark gray or very dark gray clayey gravel or gravelly clay.	10 YR 4/1 - 3/1	
		58	40	Gray to dark gray silty clay.	10 YR 5/1 - 4/1	
	431	60	25	Dark gray to very dark gray clayey peat.	10 YR 4/1 - 3/1	
	456	61	15	Gray to dary gray silty clay.	10 YR 5/1 - 4/1	
	471	70	10	Dark gray clayey peat.	10 YR 4/1	
	481	80	20	Dark gray woody peat.	10 YR 4/1	
	501					

* Munsell colors are described in wet condition

- Horse shoe
- Barbed wire
- Krotovina
- Gravel
- Burn layer
- Clay
- Silty clay
- Peat

Figure 1. Generalized stratigraphic column of the section exposed by the excavations. Most layer units can be laterally extensive and could be traced throughout the site.

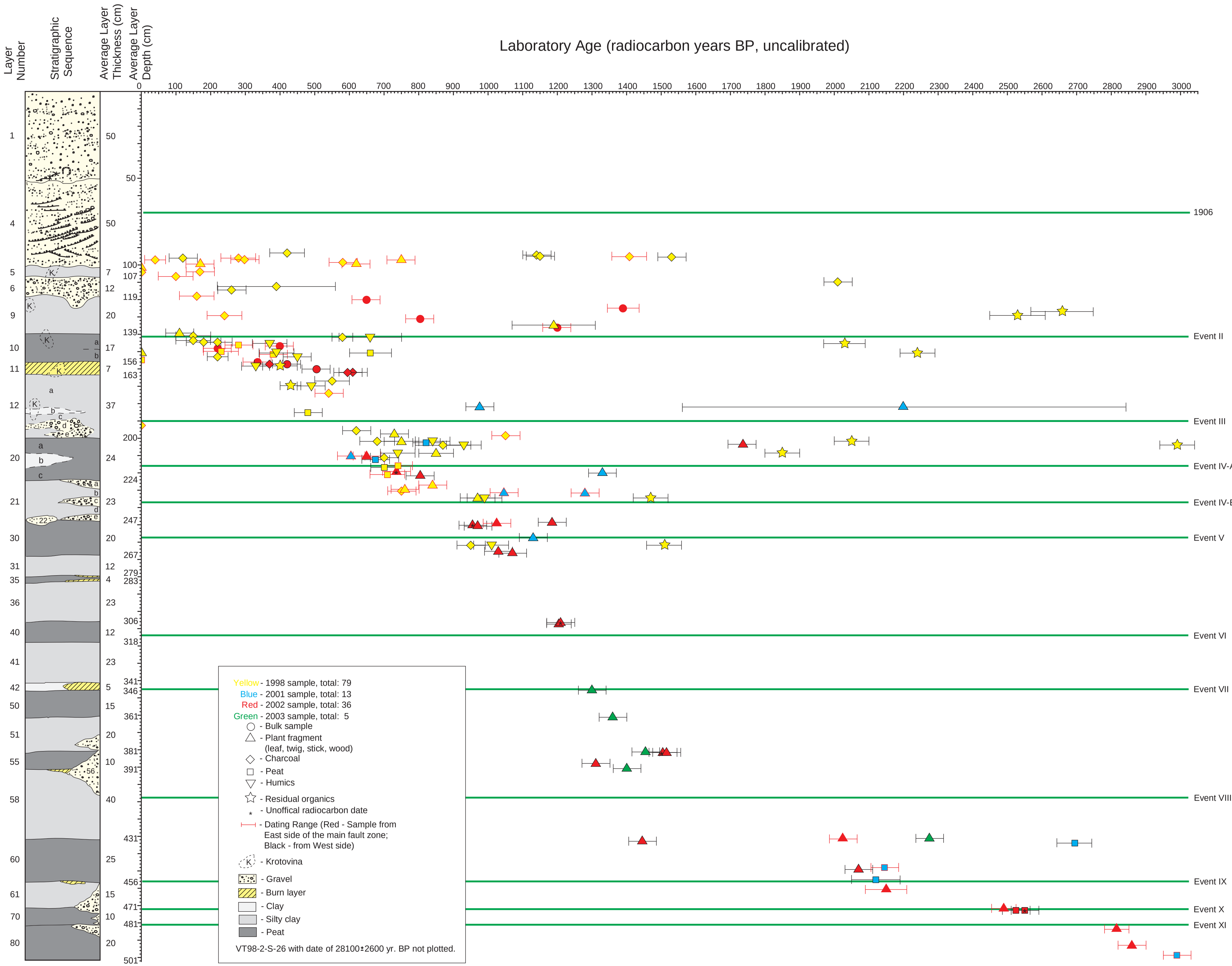


Figure 2, Scatter plot of uncalibrated radiocarbon ages versus stratigraphic sequence by depth below the ground surface. Positions of event horizons relative to the stratigraphic levels are shown as green lines.

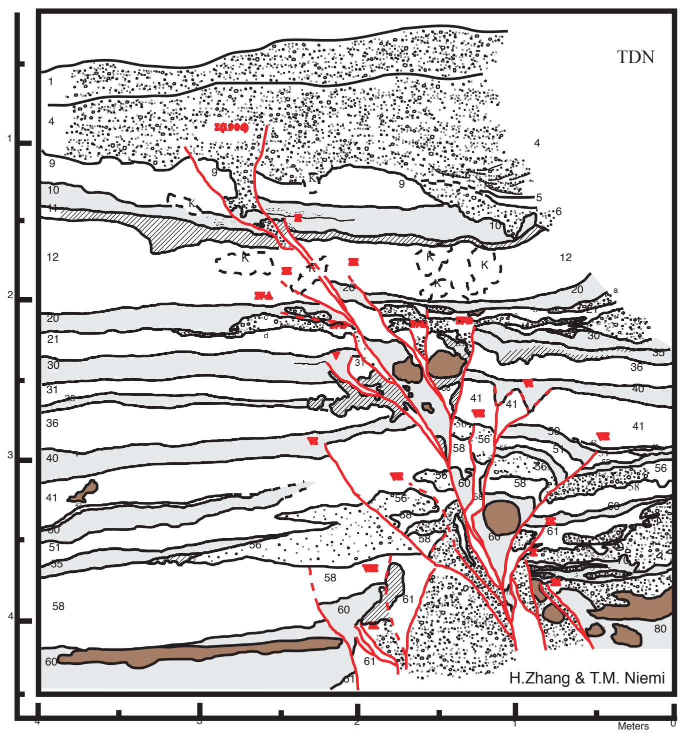


Figure 3: Prelimary Log of Trench D (V-ditch) North Wall